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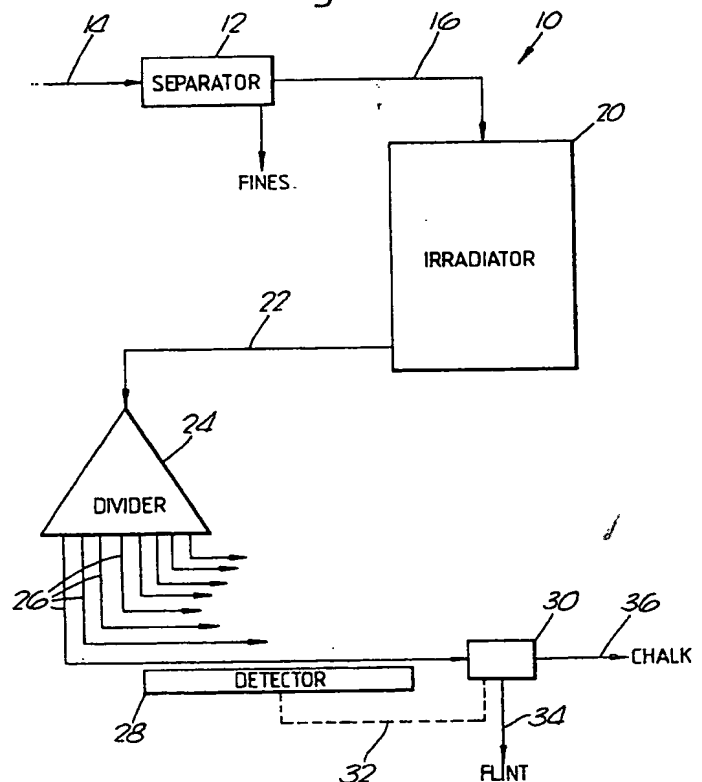
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 G01N

(54) Flint-in-chalk sorting

(57) In a method and apparatus for sorting flints from a quarried stream of lumps of chalk and flint the lumps are irradiated by fast neutrons in a chamber (20) so as to make atoms in the flint radioactive by the reaction $^{28}\text{Si}(n,p)^{28}\text{Al}$. The lumps are diverted (24) into several streams (26) and conveyed rapidly to a gamma detector (28). The lumps are then sorted (at 30) on the basis of the radiation emitted by the ^{28}Al atoms and detected by the detector. Irradiator (20) may comprise inner and outer coaxial tubes defining an annular chamber through which the lumps pass, at least one fast neutron source being mounted in the inner tube so as to be movable along a circular path concentric with the inner tube axis. A vibrating member is disposed at the bottom of the chamber and means (24) provided to split the stream of lumps into a plurality of streams (26).

Fig. 1.

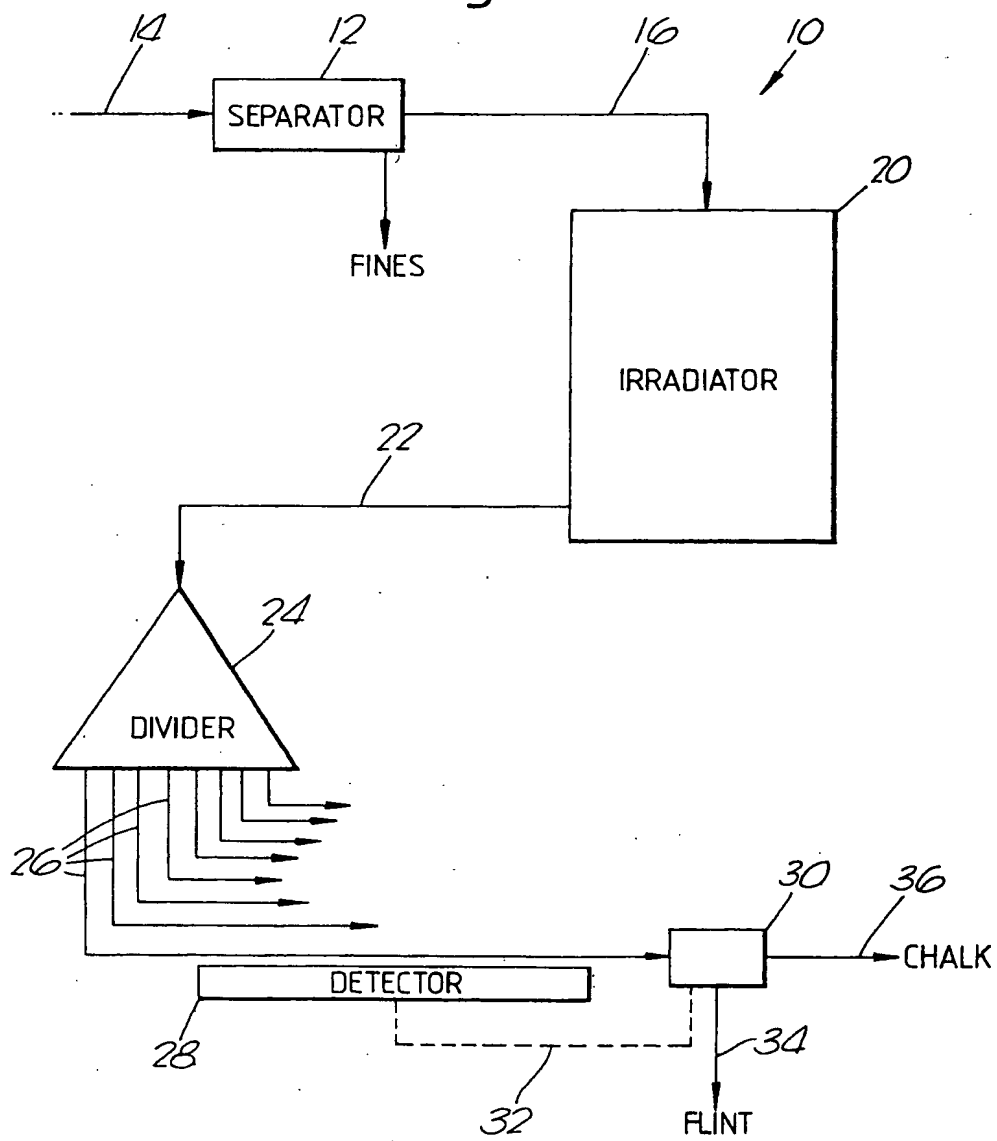


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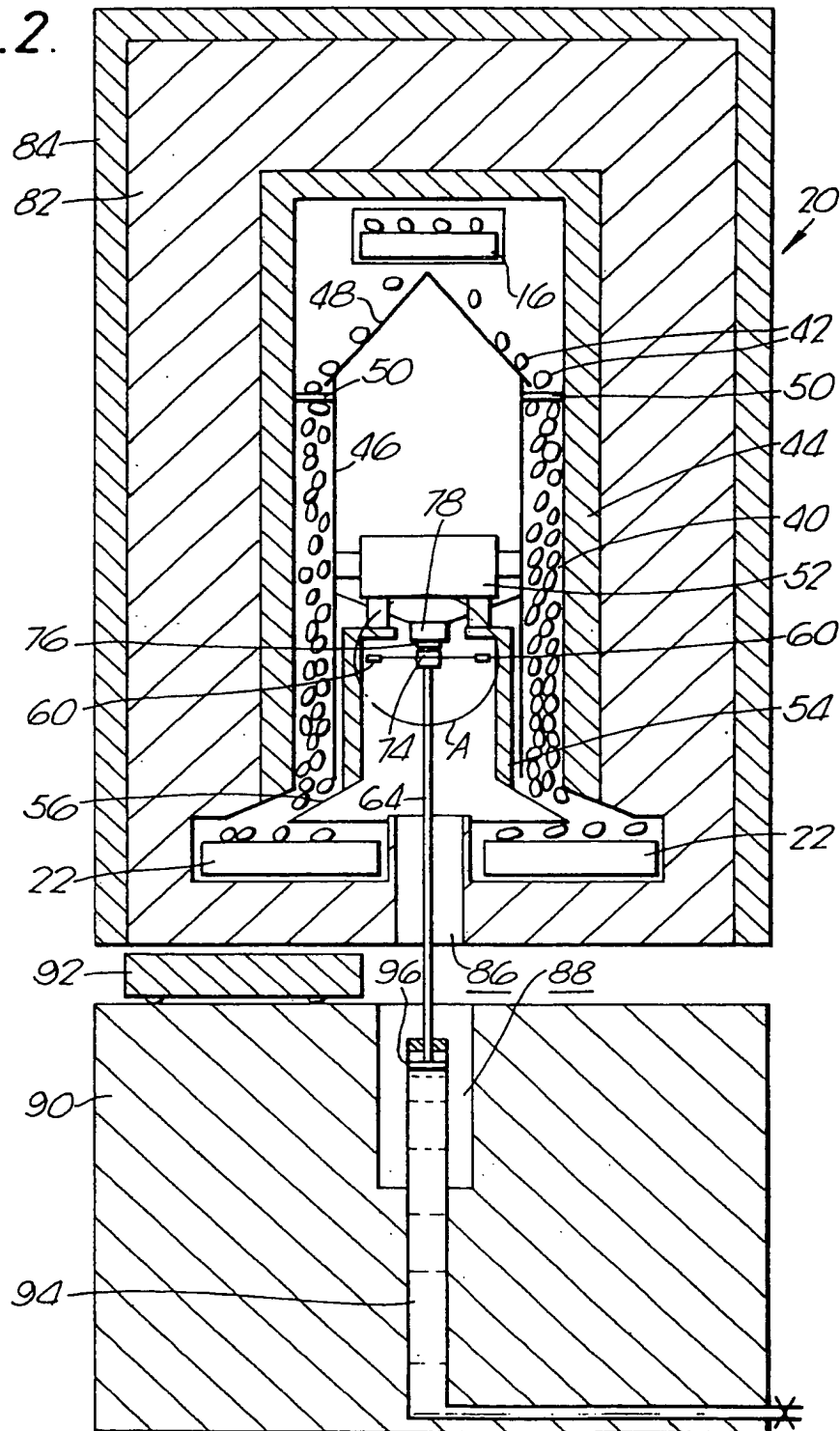
Fig. 1.



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Fig. 2.



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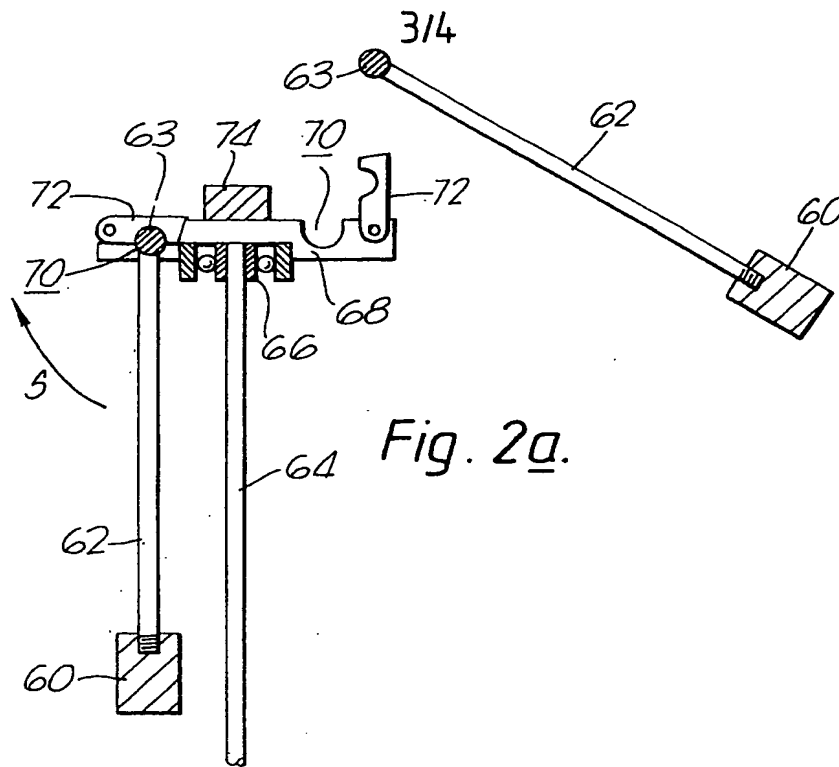
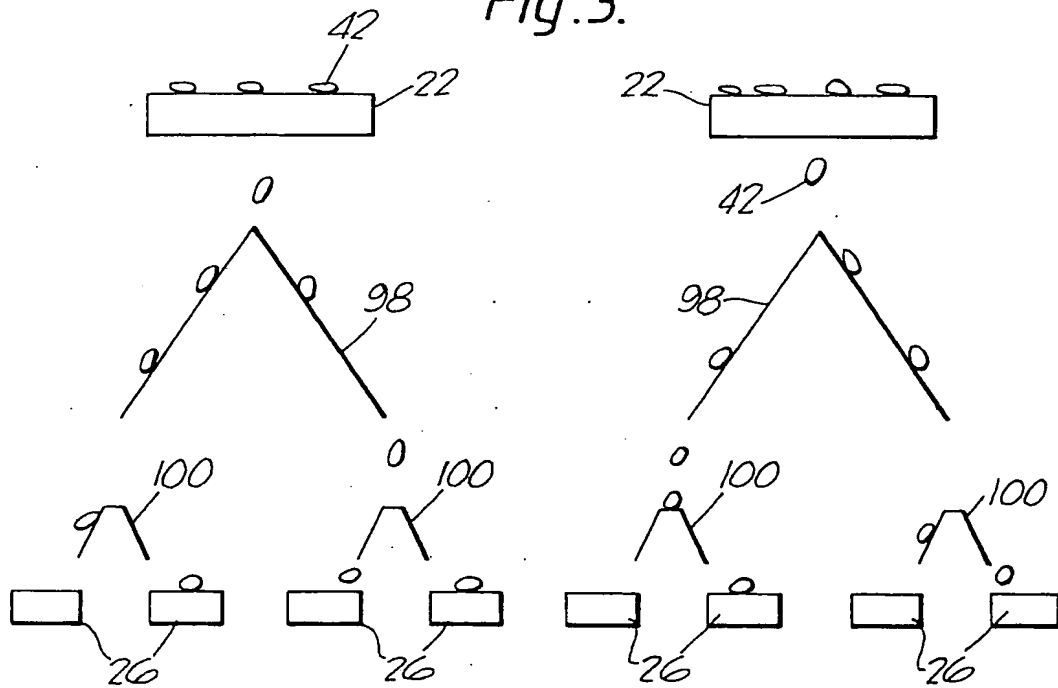


Fig. 2a.

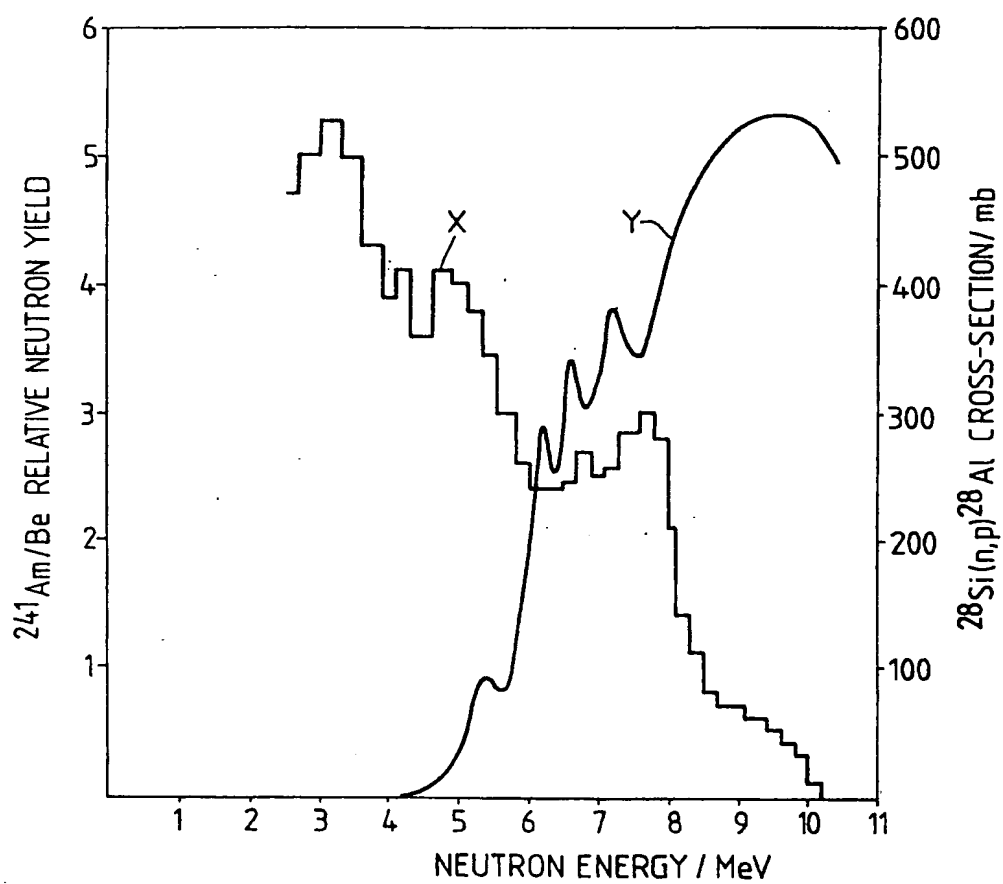
Fig. 3.



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Fig. 4.



SPECIFICATION

Flint-in-chalk sorting

- 5 This invention relates to an apparatus and a method for detecting flint in chalk and hence enabling flint and chalk to be sorted.
- Chalk deposits often contain bands of flint. Where it is desired to grind the chalk, for example in the production of a filler for paper manufacture or in cement production, the presence of the flint nodules can damage the grinding machinery. Furthermore if the flint is coloured there is a further constraint to the uses to which the ground chalk can be put.
- 10 It is customary to inspect by eye the stream of rock lumps being conveyed to the grinder and to pick out those lumps which are flint. It is difficult in practice to ensure all the flint has been detected, as many of the flint nodules have an outer surface of the same colour as the chalk; and many may be hidden within lumps of chalk. Flint is composed essentially of silica (SiO_2), while chalk consists essentially of calcite (CaCO_3).
- 25 According to the present invention there is provided a method of sorting flint from chalk in a stream of lumps of chalk and/or flint, comprising irradiating the stream of lumps with fast neutrons so as to make atoms in the flint radioactive by the reaction $^{28}\text{Si}(n,p)^{28}\text{Al}$, conveying the lumps to a detector station, detecting radiation emitted from the radioactive ^{28}Al atoms produced by the irradiation, and sorting the lumps on the basis of the detected radiation from each lump.
- 30 The invention also provides an apparatus for performing the above method.
- In the preferred apparatus the fast neutrons are provided by a $^{241}\text{Am}/\text{Be}$ source, as this source produces an adequate number of fast neutrons above the threshold energy of the reaction, which is 4.5 MeV. A preferred irradiator comprises an inner and an outer coaxial tube defining between them an annular chamber for the lumps, and at least one $^{241}\text{Am}/\text{Be}$ source within the inner tube. There may be a plurality of such sources arranged equally spaced around a circle concentric with the axis of the inner tube; alternatively the sources might be movable along such a circular path. The passage of the lumps through the chamber may be controlled by a vibrating base spaced below the bottom of the chamber.
- 55 Preferably the conveyor means incorporates means to split the stream of lumps into a plurality of streams, so as to increase the average interval between successive lumps in any one stream, and splitting may be performed on a random or a non-random basis. The detection means preferably comprises a scintillation counter, desirably a plastic scintillator, adjacent to a stream of irradiated lumps; preferably a row of such scintillation counters

is provided along and adjacent to a stream of lumps. Such scintillation counters detect gamma radiation emitted in the decay of ^{28}Al , in which a beta-particle is also emitted.

- 70 The invention will now be further described, by way of example only, and with reference to the accompanying drawings in which:
- Figure 1 shows a diagrammatic view of a flint-in-chalk sorter;
- 75 Figure 2 shows a sectional view in a vertical plane through the irradiator of the sorter of Figure 1;
- Figure 2a shows to an enlarged scale, and partly disassembled, that portion of the irradiator within the circle A of Figure 2;
- 80 Figure 3 shows a side view of part of the conveyor system of the sorter of Figure 1; and
- Figure 4 represents graphically the neutron spectrum produced by the irradiator of Figure 2, and the cross-section for the $^{28}\text{Si}(n,p)^{28}\text{Al}$ reaction
- Referring to Figure 1, a flint-in-chalk sorter 10 is shown, including a 30 mm spacing parallel-bar separator 12 to which 80 tonnes/hour quarried rock is supplied by a conveyor belt 14. Powder and small chippings of width less than 30 mm are separated off as fines, while the larger lumps of rock, typically over 50 g, are supplied by a conveyor belt 16 to an irradiator 20 described in more detail later. As a result of their passage through the irradiator any flint in the lumps will be radioactive, containing ^{28}Al which has a half-life of 2.3 minutes and decays with the emission of a beta particle and a gamma ray of energy 1.778 MeV. The irradiated lumps are conveyed by two rapid conveyor belts 22 (only one is shown) to a divider 24, described in more detail later, in which the streams of lumps are divided on a random basis into eight output streams 26 on respective rapid conveyor belts. Each output stream 26 is then conveyed past a respective detector 28 and selector 30, only those for one stream 26 being shown. Each detector 28 consists of a linear array of ten plastic scintillation blocks (e.g. Nuclear Enterprises type 102A), rectangular in shape 100 mm high 120 mm wide and 75 mm long, separated by 75 mm gaps, and each block being directly coupled to a 75 mm diameter photo-multiplier. The total count associated with each lump of rock in the respective stream 26 is accumulated, and if it exceeds a certain level indicates that the lump in question contains flint. This total count is supplied by electric cable 32 to the selector 30, and if the level is exceeded then the selector 30 is energised to divert the lump to a flint output stream 34. Undiverted lumps, which consist of chalk, emerge as output stream 36.
- Referring now to Figure 2, the irradiator 20 includes a generally upright annular chamber 40 through which the lumps 42 pass, defined

between an outer cylindrical tube 44 of lead (which acts as a fast neutron reflector and as a primary gamma ray shield), and an inner cylindrical tube 46 with a conical top 48 supported by four equally-spaced tie rods 50 (only two are shown). The chamber 40 is 1.7 m high, with an outer diameter of 1.0 m and an inner diameter of 0.6 m. The lumps 42 are fed by the conveyor belt 16 through an aperture in the outer tube 44 into the upper part of the chamber 40 so as to fall onto the conical top 48 and to be distributed uniformly around the chamber 40. Within the inner tube 46 is mounted a vibrator motor 52 supporting a tube 54 concentric with the inner tube 46 and with a conically flared skirt 56 which defines the base of the annular chamber 40. Operation of the motor 52 vibrates the skirt 56 up and down varying the width of the gap between the skirt 56 and the lower edge of the outer tube 44 and controlling the flow of the lumps 42 through this gap land on one of the two rapid conveyor belts 22.

During their passage through the chamber 40 the lumps 42 are irradiated by fast neutrons emitted by two $^{241}\text{Am}/\text{Be}$ sources 60 each of 25 curies (925 GBq). Referring now to Figure 2a, each source 60 is attached to one end of a support rod 62 which at its other end is T-shaped; the cross-piece 63 of the T is cylindrical. A vertical support arm 64 is coaxial with the annular chamber 40 and to its top end are mounted, by means of a ball race 66, two parallel spaced apart brackets 68 (only one is shown) each with semi-circular notches 70 on its upper edge near each end. The cross-pieces 63 locate in these notches 70 so that the support arms 62 can swing freely, and when in that position the cross-pieces 63 are secured by spring-loaded safety clips 72. On top of the brackets 68 is mounted a magnet 74, which when the support arm 64 is in the operating position as shown in Figure 2 is adjacent a magnet 76 rotatable by an electric motor 78 mounted below the vibrator motor 52. When the irradiator 20 is in operation the motor 78 is energised, so rotating the magnet 74 and the brackets 68, and the support rods 62 and sources 60 swing out (indicated by arrow S) to follow a circular path just inside the tube 54; the motor 78 is energised to rotate the sources 60 at about 50 rpm. This ensures uniformity of irradiation all round the chamber 40.

The irradiator 20 includes two further layers of shielding outside the outer cylindrical lead tube 46: a borated polystyrene neutron shield 82 which extends below the rapid conveyor belts 22, and a capture gamma-ray shield 84 of lead outside the neutron shield 82. An axial hole 86 through the neutron shield 82 in the base of the irradiator 20 enables the support arm 64 and with it the sources 60 to be

withdrawn, when not in use, into a recess 88 in a massive concrete shielding block 90 below the irradiator 20; the top of the recess 88 can then be covered by a lead lid 92 on rollers. Raising and lowering of the support arm 64 is accomplished by means of a hydraulic cylinder 94 and a piston 96 to which the support arm 64 is joined.

Referring now to Figure 4, which shows graphically the neutron spectrum produced by the sources 60 (graph X), and the cross-section in millibarns for the reaction $^{28}\text{Si}(n,p)^{28}\text{Al}$ (graph Y), it will be observed that the sources 60 produce neutrons of energy up to 10 MeV. The reaction can be seen from graph Y to have a threshold at about 4.5 MeV, and has a cross-section of about 300 mb for neutrons of energy between about 6.5 MeV and 8 MeV. Many of the neutrons emitted by the sources 60 are therefore able to bring about the desired reaction.

The ^{28}Al atoms produced by the irradiation of the flint have a half-life of 2.3 minutes, so to maximize the count received by the detector 28 (see Figure 1) it is important that the lumps of rock emerging from the irradiator 20 are conveyed to the detectors 28 rapidly, preferably in a time less than the half-life. The irradiator 20 receives about 52 tonnes/hour of lumps of average size about 150 g; that is to say that about 96 lumps/second emerge from the irradiator 20 and must be conveyed to the detectors 28. It is desirable that at the detector 28 any one scintillation block receives gamma rays from only one lump at any one time, and it is therefore desirable to space the lumps out before they reach the detector 28. The spacing out is partly achieved by use of the rapid conveyor belts 26, and partly by the divider 24.

Referring to Figure 3, the divider 24 splits the two streams of lumps 42 from the belts 22 into eight outlet streams on rapid conveyor belts 26. Lumps 42 fall off a conveyor belt 22 and are split into two channels by an inverted-V-shaped member 98. They then fall onto a further inverted-V-shaped member 100 which diverts them onto one of the belts 26; the members 100 are located such that lumps 42 falling onto them have equal probability of being diverted in either direction, and are flat-topped. Any lump which lands and rests on a flat-top will be knocked off by a subsequent lump, and the two lumps almost certainly fall on opposite sides of the member 100 to land on different belts 26. As a consequence of their passage through the divider 24, the lumps 42 are less likely to be close together on the belts 26, and the average number of lumps 42 on any one is reduced to 12 lumps/second. The conveyor belts 26 transport the lumps 42 at 2 m/s, so on average the spacing of the lumps is 165 mm, which is greater than the separation between adjacent scintillation blocks in the detectors 28.

In the sorter 10 the separator 12 is used only to separate off fines, that is lumps below a certain size. It will be appreciated that if desired means (not shown) may be provided to separate off excessively large lumps, and so further limit the range of sizes to be sorted. If desired, the detector 28 might utilize alternative gamma detectors such as sodium iodide (thallium activated) scintillators in place of plastic scintillation blocks; and might incorporate means for discriminating between gamma rays of different energies.

It will be appreciated that the apparatus may differ in many details from that described above while remaining within the present invention. For example the irradiator 20 incorporates a chamber 40 which is annular and within which the lumps are irradiated by two rotating fast-neutron sources 60. An alternative irradiator (not shown) incorporates a generally rectangular, open-ended chamber 2.25 m high, of square cross-section with rounded corners, opposite walls being 1.0 m apart; about 200 mm below the bottom of the walls are two outwardly sloping vibrator trays which discharge the irradiated lumps onto two rapid conveyor belts similar to those described earlier. Within this chamber are fixed four vertical tubes each of diameter 60 mm arranged at the corners of a square of sides 530 mm (the sides of this square being parallel to the walls of the chamber), and a 15 curie fast neutron source is located in each tube at a distance of 600 mm above the vibrator trays. When the irradiator is not in use each source is raised into a shielded source store situated above the irradiator. This irradiator operates in a similar fashion to that described earlier, though in this case the sources remain stationary during operation.

In the sorter of Figure 1 the rapid conveyor belts 26 are described as transporting the lumps at 2 m/s, though the belts might instead operate still faster, for example at 6 m/s, so separating successive lumps still further apart. Furthermore the divider 24 splits the streams of lumps on the belts 22 into outlet streams in a purely random basis, relying as it does on the lumps being distributed substantially at random over the width of the belts 22. Instead the divider might incorporate non-random dividing means: the lumps might be aligned and then successive lumps diverted to two alternate streams, possibly after allowing the lumps to separate by free fall. Such a non-random division ensures that successive lumps on the belts 26 cannot be in contact, so making the counting more reliable.

It will also be appreciated that the detector 28 might have a different number of scintillation blocks to that described; it is desirable to accumulate the total count associated with a single lump for a time of about 1 second (or more), so that if the belts 26 operate at 6 m/s instead of 2 m/s the number of scintilla-

tion blocks is desirably increased from ten to thirty to ensure the same counting time. In addition each block is desirably surrounded on each side by lead shielding, to minimize the detection of radiation emitted by lumps other than the one passing at that instant over the block.

CLAIMS

1. A method of sorting flint from chalk in a stream of lumps of chalk and/or flint, comprising irradiating the stream of lumps with fast neutrons so as to make atoms in the flint radioactive by the reaction $^{28}\text{Si}(n,p)^{28}\text{Al}$ conveying the lumps to a detector station, detecting radiation emitted from the radioactive ^{28}Al atoms produced by the irradiation, and sorting the lumps on the basis of the detected radiation from each lump.
2. A method as claimed in Claim 1 wherein the lumps are irradiated during passage through an irradiator chamber with an outlet port for the lumps at its bottom, and the passage of the lumps therethrough is controlled by a vibrating member spaced below the bottom of the chamber.
3. A method as claimed in Claim 1 or Claim 2 also including dividing the stream of lumps into a plurality of streams to increase the average spacing between successive lumps.
4. A method as claimed in Claim 3 wherein the dividing operation is performed on a non-random basis.
5. An apparatus for sorting flint from chalk in a stream of lumps of chalk and/or flint, comprising an irradiator for irradiating the stream of lumps with fast neutrons so as to make atoms in the flint radioactive by the reaction $^{28}\text{Si}(n,p)^{28}\text{Al}$ means for conveying the lumps to a detector station, means for detecting radiation emitted from the radioactive ^{28}Al atoms produced by the irradiation, and means for sorting the lumps on the basis of the detected radiation from each lump.
6. An apparatus as claimed in Claim 5 wherein the irradiator includes a $^{241}\text{Am}/\text{Be}$ source to provide fast neutrons.
7. An apparatus as claimed in Claim 5 or Claim 6 wherein the irradiator comprises an inner and an outer coaxial tube defining between them an annular chamber for the lumps, and at least one fast neutron source within the inner tube.
8. An apparatus as claimed in Claim 7 wherein the or each neutron source is arranged to be movable along a circular path concentric with the axis of the inner tube.
9. An apparatus as claimed in any one of Claims 5 to 8 wherein the irradiator comprises a chamber with an outlet port for the lumps at its bottom, and the apparatus includes a vibrating member spaced below the bottom of the chamber for controlling passage of lumps through the chamber.
10. An apparatus as claimed in any one of

Claims 5 to 9 wherein the conveyor means incorporates means to split the stream of lumps into a plurality of streams, so as to increase the average interval between successive lumps in any one stream.

5 11. An apparatus as claimed in Claim 10 wherein the splitting means is arranged to split the stream on a non-random basis.

12. An apparatus as claimed in any one of
10 Claims 5 to 11 wherein the conveyor means incorporates means for transporting the lumps at a speed greater than 1 m/s.

13. An apparatus as claimed in any one of
Claims 5 to 12 wherein the detection means
15 comprises a row of scintillation counters along and adjacent to a stream of lumps.

14. An apparatus as claimed in Claim 13 wherein radiation shielding material is provided between adjacent counters in the row.

20 15. A method of sorting flint from chalk substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

16. An apparatus for sorting flint from chalk
25 substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

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